Los Alamos National Laboratory

Advances in fuel cells

By Rod Borup[1]

Christina Johnston screens materials for use as oxygen reduction catalysts in fuel cells.

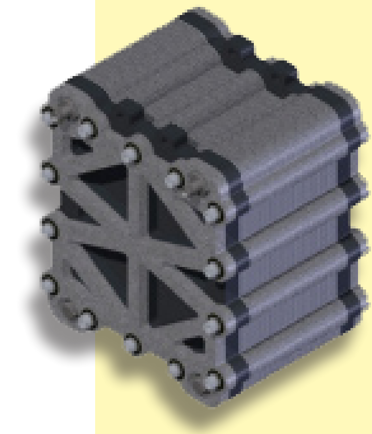
Fuel cells are not exactly a contemporary development, unless you consider 1839 to be contemporary, since that was the year the fuel cell was invented. They powered the Gemini and Apollo space missions and still provide power on the space shuttle. But perfecting them for commercial use by making them more cost-effective and durable still poses challenges. Since the 1970s, scientists at Los Alamos National Laboratory have provided a number of scientific and technical breakthroughs that have already contributed to the development of modern fuel cell systems

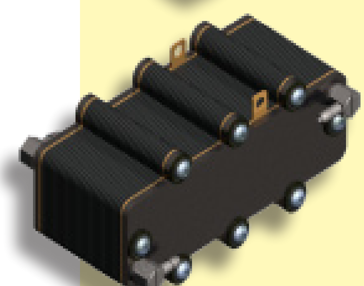
Hydrogen fuel cells can be built to any size, which means they can power anything from a cell phone, which takes about one watt of electricity, to an automobile, which requires about 130 kilowatts. Potential applications are plentiful and include the use of fuel cells for powering small electronics (such as cell phones and laptop computers), providing power for homes, and serving as auxiliary power (in trucks, buses, cars and RVs) and as back-up power for increasing grid reliability.

While fuel cells will likely be implemented first for stationary and portable use in homes and for consumer electronics, their greater efficiency and eco-friendliness make their use for powering vehicles the ultimate goal. Efficiency, as compared with conventional internal combustion engines, is the biggest advantage of using fuel cells for transportation. A gasoline-powered engine is only about 22 percent efficient, meaning that only about 22 percent of the energy in the onboard fuel actually powers the vehicle; the remainder is wasted as heat. A diesel-powered vehicle runs at about 27 percent efficiency, a hybrid electric vehicle at about 30–35 percent. In contrast, hydrogen cell vehicles can run at 55 percent efficiency. Fuel cells simply consume less fuel for the same power output, which could reduce U.S. energy consumption overall and, when expanded to transportation, shrink the country's dependence on foreign oil.

Another advantage is the environmental impact of fuel cells. Hydrogen fuel cells emit no pollution because they produce electricity from oxygen and hydrogen, releasing only water into the atmosphere. One day soon, if fuel cells replace internal combustion engines, our cars could burn less fuel and give off no harmful emissions.

Fuel cells are similar to batteries in that they convert chemical energy into electricity. Unlike batteries, however, they use fuel that is external to the fuel cell. The main type of fuel cell being developed at Los Alamos converts hydrogen and cells use catalysts made of platinum to convert hydrogen into protons and electrons. The protons pass





Top: Fuel cell stack. Multiple individual cells are combined in series to form "stacks" to achieve a useable voltage. Above: Los Alamos direct methanol fuel cell stack technology for portable power. Below: Hydrogen fuel cell-powered personal mobility vehicle ("scooter"). Scooter has passive air breathing stack (~ 200 W/module) and on-board stored H_2. An air fan is the only moving part of the fuel cell system.

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through a membrane (at the center of the fuel cell) and combine with oxygen and with electrons on the other side, producing water. The electrons flow through an external circuit containing a motor or other electric load, which consumes the power generated by the cell.

Scientists in the fuel cell program are working to address all parts of this conversion process to overcome the challenges associated with fuel cells, thereby decreasing' cost and increasing their performance and durability. The lab's focus includes decreasing the cost of the catalyst, improving the materials that make up the membranes, understanding what degrades the performance of fuel cells (including the effects of fuel and air impurities), and understanding water management inside the cell.

One of the biggest issues is the high cost of the platinum for the electrocatalyst. To lower costs, the amount of platinum must be reduced from current usage levels without losing performance, or a new catalyst must be developed that does not rely upon expensive noble metals. Scientists have developed new classes of hydrogen fuel cell catalysts made of low-cost nonprecious metals entrapped in heteroatomic polymeric structures. As replacements for platinum, these new catalysts exhibit promising activity and stability.

Durability is another issue scientists are addressing. Los Alamos is examining the fundamental degradation mechanisms in fuel cells in order to develop mitigation strategies. By understanding changes to material properties, they are able to develop advanced materials and modify operating strategies to reduce degradation. For example, catalysts lose reactivity during their use, and this has been seen especially in tests simulating vehicle operation. One reason for lost reactivity is the tendency of the platinum particles to grow. The larger the particles, the lower the activity per mass of platinum. Putting in more platinum is one strategy, but unfortunately that also raises costs. Loss of catalyst reactivity is not the only durability issue. The membrane can also form pinholes or thin over time, both of which can degrade performance. The membrane itself is expensive as well, so materials are being developed to lower these costs.

Los Alamos scientists have also made significant progress in understanding the behavior of fuel impurities in hydrogen fuel cells. The best fuel cell performance occurs when the fuel cell is supplied with ultrapure hydrogen and air, but fuel cells will have to co-exist with other current technologies and rely upon the quality of air that is present. With that in mind, researchers are studying the migration of impurities in fuel cells and the exact mechanisms at work in performance inhibition. Small amounts of hydrogen sulfide lower the kinetics of the oxygen reduction reaction on platinum surfaces due to poisoning of the catalyst. These studies will result in an understanding that will help define what quality of hydrogen is required and what air purification might be required.

Since the 1970s, scientists at Los Alamos National Laboratory have provided a number of scientific and technical breakthroughs that have already contributed to the development of modern fuel cell systems. Above, liquid hydrogen storage tanks fill the trunk of this 1970's Buick, one of the first hydrogen vehicles. Los Alamos researchers modified the internal combustion engine to operate on hydrogen, in response to the first oil embargo.

Ineffective control of water distribution can be a major impediment to implementing polymer electrolyte membrane fuel cells (PEMFCs). Components such as the polymer electrolyte membranes (PEMs) and electrode layers require the presence of sufficient water in order to allow adequate proton conductivity across the membrane. Conversely, excess water within the system leads to mass transfer losses and can require additional costs (extra energy or weight for increased humidification.) Scientists are working to understand water transport within fuel cells by developing in situ techniques of looking at water inside operating fuel cells. Two advanced techniques the laboratory has implemented are neutron imaging and x-ray tomography, which allow visualization of water distribution during fuel cell operation. The advanced measurements obtained through these technologies provide a better understanding of how material properties affect fuel cell transport processes, and that understanding contributes to the optimization of fuel cell performance.

Beyond the technical challenges, fuel cell acceptance may require a sea change in the public's thinking. Full implementation into the commercial sector requires displacing existing technologies, a daunting challenge that requires fuel cells to be superior to the technologies they replace. Implementation will also require educating the public about the benefits of fuel cells and the safety of the hydrogen fuel. To begin to adjust the American mindset, the world's major automakers are rolling out prototypes of fuel cell cars. Prototype fuel cell forklifts and buses are already in use around the globe, as are stationary power supplies for buildings.